WATER UTILIZATION BY WINTER WHEAT

M. Entz, D. B. Fowler and E. de Jong

Crop Development Centre and Saskatchewan
Institute of Pedology, University of
Saskatchewan

Introduction

It has often been stated that water is the single most important factor governing crop production in the prairie provinces. This paper will review experiments which were established with the purpose of determining the extent to which water limits yields of winter wheat in Saskatchewan.

Crop response to water is often expressed in kg grain/ha per centimeter of water transpired or per cm potential evapotranspiration (PET) and is described by the term water use efficiency (WUE). WUE of 70-120 kg/ha/cm were recorded for spring wheat by Staple and Lehane (1954 a,b) and de Jong and Rennie (1967). More recently, Kachanoski et al. (1985) reported WUE for spring wheat ranging from 100-270. These relatively high responses to water indicate that water is responsible for a major portion of grain yield. It should be noted that while WUE has provided a useful measure, high WUE is not necessarily an indicator of high yield. For instance, WUE can be increased with increased nitrogen fertility (de Jong and Cameron, 1980). Also, variation in WUE for similar yields will occur and is due to variation in PET. This was observed by Kachanoski et al. (1985)

when they measured WUE along a catenary sequence.

Winter wheat usually outyields spring wheat in Saskatchewan. It has been suggested that maximum potential yields for Norstar winter wheat in the parkland region of the prairies could be 5000-6000 kg/ha Rourke (1985). de Jong and Steppuhn (1983) suggested that winter wheat may use water more efficiently because of differences in growth habit. WUE of winter wheat was reported for Montana conditions by Brown and Black (1983). They reported a WUE of 108 kg/ha/cm for problem growing conditions and 180 kg/ha/cm for ideal growing conditions. The first objective of this study was to investigate the limitation of water to achieving maximum potential yields of winter wheat.

A second objective of this study was to determine at which crop growth stage water was most limiting. Analysis of particular yield components such as tiller production, seeds per head and seed size have been used by many workers to allow some indication of stress at different growth stages (Eastin et al. 1983).

Materials and Methods

Field experiments were conducted at Saskatoon (1984 and 1985), Outlook (1985) and Clair (1985). Individual plots were 20 m square in area and four replicates of each treatment were used. Norstar winter wheat was planted at a seeding rate of 75 kg/ha. Thirty kg/ha phosphorous were applied with the seed. Nitrogen fertilizer (34-0-0) was broadcast in early spring. Rates used were according to soil test recommendations. It should be noted that residual soil N levels were exceptionally high at Saskatoon in 1985 (260 kg/ha in top 120 cm).

Soil water depletion to 120 cm depth was measured over the period May 15 to harvest using a neutron probe. Surface moisture (0-10cm) was determined gravimetrically). Total water use was calculated as the change in storage (spring - harvest) plus precipitation and irrigation. Supplemental water was applied to the plots designated for irrigation beginning in early June: Outlook-June 7; Clair-June 12; Saskatoon 1984-June 5 and Saskatoon 1985-June 11. Water was applied using a trickle irrigation system at Clair and Saskatoon (1985) while flood irrigation was used at the other sites. Amounts of applied water ranged from 25 to 60 mm per irrigation. A goal of 130% normal growing season precipitation for each site was set. One hundred and thirty percent normal growing season precipition occurs in the Saskatoon area with a probability of 25%. Sites were irrigated 3-4 times during the growing season and total amounts of irrigation water were as follows: Saskatoon 1984 - 200 mm; Saskatoon 1985 - 125 mm; Clair - 82 mm and Outlook - 122 mm.

Prevailing climatic conditions were monitored and growing degree days were calculated using 5 C as a base temperature. Evaporation was measured using Class A evaporation pans and moisture deficits were calculated as evaporation minus precipitation and irrigation.

Prior to combine harvesting a portion of each plot was harvested for use in yield component analysis. Protein content is expressed on a dry weight basis.

Water use efficiency was calculated as grain yield (kg/ha) per cm total water use (cm). Because these calculations were based on the May 15 - harvest period, WUE will be underestimated as water used to establish early vegetative growth was not accounted for.

Results and Discussion

Climatic conditions - A summary of prevailing climatic conditions is shown in Table 1. Growing season precipitation

Table 1. Climatic Data: May 15 to August 15

	Climatic Parameters		
Location	Precipitation mm	Evaporation mm	Growing Degree Days
Saskatoon 1984	89	788	1191
Saskatoon 1985	99	621	1041
Clair 1985	150	368	820
Outlook 1985	55	698	1052

was low at most locations, ranging from 35 to 86% of normal (Table 2). The greatest differences in climatic conditions were between Clair and the other sites. Clair had a lower moisture deficit (Table 3) and fewer growing degree days (Table 1).

Table 2. Percent Normal Precipitation: May 15 to August 15

Location	Dryland	Irrigation
Saskatoon 1984	51%	166%
Saskatoon 1985	56%	129%
Clair 1985	86%	133%
Outlook 1985	35%	113%

Table 3. Moisture Deficit: May 15 to August 15

	Moisture deficit (mm)[1]	
Location	Dryland	Irrigation
Saskatoon 1984	699	499
Saskatoon 1985	522	397
Outlook 1985	643	521
Clair 1985	218	136

[1] Moisture Deficit = Evaporation - Precipitation + Irrigation

Response to water - Responses to additional moisture were found to be statistically significant for grain and total biological yield at all locations (Table 4). Average yields for Norstar

Table 4. Yield and Water Use of Norstar Winter Wheat

Location		Grain yield kg/ha	Total dry wt kg/ha	Protein %	Harvest index %	Total water use mm	Wue kg grain per cm
Saskatoon 1984	I	3413	10000	12.4	35.4	285	119
	D	1495	3380	13.5	56.4	127	117
		*	*				
Saskatoon 1985	I	4366	13800	13.9	46.6	233	186
	D	3016	10130	13.6	42.3	106	282
		*	*	N.S.	N.S.	*	*
Clair 1985	I	3010	9793	12.1	41.0	236	127
	D	2408	7293	12.8	54.4	155	154
		*	*	N.S.	N.S.	*	*
Outlook 1985	I	2251	10350	14.8	27.8	183	128
	D	1317	7380	15.2	21.7	60	214
		*	*	N.S.	N.S.	*	*

I irrigation
D dryland

* Significant at 5%   N.S. Not significant

over all locations were 2059 and 3260 kg/ha for dryland and irrigation treatments, respectively. The highest yield recorded was under irrigation at Saskatoon 1985 (4366 kg/ha). The relative responses increased with moisture deficit; relative increases in grain yield were 25, 44, 70 and 128 % for moisture deficits of 218, 522, 643 and 699 mm, respectively. These results indicate that water does in fact appear to be the environmental factor which is most limiting to winter wheat yield, even where growing season precipitation is near normal (Clair 1985).

Protein contents were not significantly affected by additions of water (Table 4) however they were somewhat lower for irrigation treatments in some cases. The lack of response in protein would indicate that nitrogen levels were reasonably adequate at all locations.

Table 5. Yield and Water Use of Norwin Winter Wheat. Saskatoon 1985

Water tmt	Grain Yield kg/ha	Total dry wt kg/ha	Protein %	Harvest index %	Total water use mm	WUE kg grain per cm
irrig.	4920	12070	13.3	68.8	230	213
dryland	3186	9690	12.7	48.9	103	309
	*	N.S.	N.S.	*	*	*

* Significant

N.S. Non-significant

Water use efficiencies for Norstar ranged from 117 to 283 kg/ha/cm (Table 4) with an overall mean of 166. Mean WUE was 192 for dryland and 140 for irrigated conditions, respectively.

Lower WUE for irrigated treatments may indicate that other factors such as soil fertility were limiting grain yield.

Grain yield was significantly (P=.05) related to total water use (Figure 1a). Water accounted for 42% of the variablilty in yield. When the site with exceptionally high nitrate-N (Saskatoon 1985) levels was excluded, 92.7% of the variability in yield was explained by the amount of water present (Figure 1b). These observations indicate that 1) water is the major environmental factor limiting yield and 2) the relationship between water and grain yield can be influenced by soil N status. Higher N levels have been found to result in higher water use efficiencies (de Jong and Cameron 1980). Observations here would also suggest that in order to achieve maximum grain yields, both water and nitrogen levels must be adequate.

Yield Components - Yield components for Norstar winter wheat are shown in Table 6. While dryland treatments generally resulted in reduction of individual components, only fertile tiller production and seed weight were significantly affected. This indicates that water was most limiting at the earlier growth stages at Outlook and Clair and at later stages at Saskatoon. This evidence will be pooled with measurments of plant physiological function in an attempt to further identify critical stress periods. Results will not be reported here.

Semi-dwarf character - Agronomically successful semi-dwarf cultivars often have higher grain to straw ratios than normal

Figure 1. Relationship between total water use and grain yield for 1984 and 1985: Norstar winter wheat.

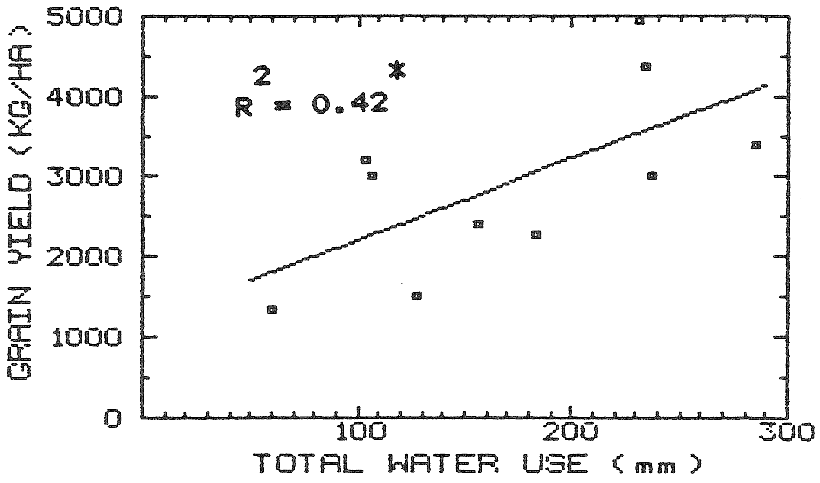

Figure 1a

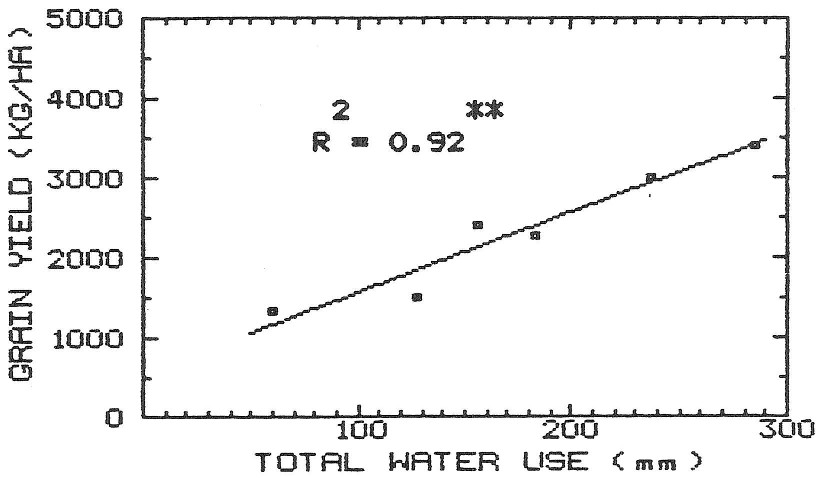

Figure 1b

* Significant at 5%

** Significant at 1%

Table 6. Yield Components for Norstar Winter Wheat 1985.

Location	Water tmt	Fertile tillers per m2	Kernels per spike	1000 kernel wt g	? Sign. Yield response
Outlook	irrigation	515	37.5	25.1	
	dryland	388	34.4	23.2	
		*	N.S.	N.S.	YES
Saskatoon	irrigation	466	43.7	38.3	
	dryland	389	39.3	34.0	
		N.S.	N.S.	*	YES
Clair	irrigation	373	33.6	31.7	
	dryland	266	34.6	31.4	
		*	N.S.	N.S.	YES

* Significant at 5%

N.S. Non-significant

height cultivars and may have a yield advantage. The semi-dwarf winter wheat cultivar "Norwin" was included in the experiment at Saskatoon in 1985 (Table 5). Yields were comparable to those of Norstar under dryland conditions but were greater under irrigated conditions. The yield implications of semi-dwarf cultivars can only be speculated on at this time. Semi-dwarf cultivars may be better suited for wetter areas of the province.

Summary and Conclusions

Water accounted for much of the variability in grain yield. It was therefore concluded that water is the major environmental factor limiting grain yield of winter wheat even where growing season precipitation is near normal.

Grain yield was closely related to total water use. Water use efficiency for winter wheat was found to range from 117 to 282 kg/ha/cm with an overall mean of 166 kg/ha/cm.

Water stress was found to occur at several different stages throughout the crops growth period.

Nitrogen status of the soil can influence water utilization of winter wheat.

Semi-dwarf cultivars hold promise for increased yields.

Literature Cited

Brown P.L. and A.L. Black 1983. Stubble seeding and fertilization of winter wheat. In: New Frontiers in Winter Wheat Production. Fowler, Gusta and Slinkard (eds.) Western Can. Winter Wheat Conf. June 20-22, 1983. University of Saskatchewan, Saskatoon, Sask.

Eastin J.D., R.M. Castleberry, T.J. Gerik, J.H. Hultquist, V. Mahalakshmi, V.B. Ogunlenla and J.R. Rice 1983. Physiological aspects of high temperature and water stess. p 91-112. In C.D. Raper, Jr. amd P.J. Kramer (ed.) Crop reaction to water and temperature stresses in humid, temperate climates. Westview Press, Boulder, Colorado

de Jong E. and D.A. Rennie 1967. Physical soil factors influencing the growth of wheat. In Canadian Centennial Wheat Symposium. K.F. Nielsen (ed.) Modern Press, Saskatoon, Sask.

de Jong E. and D.R. Cameron 1980. Efficiency of water use by agriculture for dryland crop production. Prairie Production Symp.,Soils and Land Resources, Advisory Comm. to the Canadian Wheat Board, Saskatoon.

de Jong E. and H. Steppuhn 1983. Water conservation in the Canadian Prairies. In Dryland Agriculture. H.E. Dregne and W.O. Willis (ed.) Agronomy 23 : 89-102.

Kachanoski R.G., R.P. Voroney, E. deJong and D.A. Rennie 1985. The effect of fall stubble management on over-winter recharge and grain yield. Soils and Crops Workshop Meetings, February 20 and 21, 1985, Saskatoon, Sask.

Rourke D. 1985. Intensive management for winter wheat. U.G.G. Publication: Grain Grower, Feb. 21, 1985.

Staple W.J. and J.J. Lehane 1954a. Wheat yield and use of moisture on substations in southern Saskatchewan. Can. J. Agric. Science 34: 460-468.

Staple W.J. and J.J. Lehane 1954b. Weather conditions influencing wheat yield in tanks and field plots. Can. J. Agric. Science 34: 552-564.